Best Available Control Technology (BACT) Analysis:
Ultra-Low NOx Burners on Natural Gas Fired Boilers

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9/27/2022

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I. Introduction

The Utah Division of Air Quality (UDAQ) is considering regulating natural gas-fired boilers used in industrial, institutional, and commercial operations in Salt Lake, Davis, Weber, and Tooele counties. The proposed regulation would require owners and operators of natural gas-fired boilers greater than 2MMBtu/hr to install ultra-low NOx burners when replacing a boiler or a boiler's burner. Ultra-low NOx burners, burners capable of producing less than 9 parts per million (ppm) NOx, have been required in other ozone nonattainment areas (NAA) around the country. Therefore, UDAQ's planning department decided to conduct research to determine if this technology was economically feasible according to BACT guidelines.

The potential rules regulating natural gas-fired boilers would be divided into two categories, 2-5MMBtu/hr boilers and boilers greater than 5 MMBtu/hr. Therefore, a cost analysis for both of these categories was conducted.

II. Methods

The UDAQ reached out to about a dozen boiler manufacturers to acquire quotes on boilers of specific sizes. Of the manufacturers contacted, four manufacturers provided estimates on a total of ten boilers. The majority of these boilers were rated at 9 ppm NOx however, several of them were rated at variously higher ratings of NOx. The UDAQ requested estimates on boilers with higher NOx ratings for comparison purposes.

The majority of the quotes received were for the full boiler and burner replacement. At this time the UDAQ will not be requiring immediate retrofits. The UDAQ decided that it would be better to require that boilers and/or their burners be upgraded to ultra-low NOx systems as they were naturally replaced. This cost analysis found that full replacement, as calculated by the worst-case scenario BACT cost is cost-effective. Therefore, if replacing the entire boiler is cost-effective according to BACT guidelines, replacing only the burner should be cost-effective as well. Replacing an end of life burner with an ultra-low NOx burner cannot cost more than the full replacement of the boiler.

Additionally, the majority of the quotes received are for smaller boilers. The UDAQ requested quotes on smaller boilers because the larger the boilers get, the more cost-effective the use of ultra-low NOx burners becomes due to increased emissions. The UDAQ's permitting department has processed dozens if not hundreds of larger boiler replacements and retrofits. These projects are almost always cost-effective. One quote for a low NOx to ultra-low NOx retrofit on a 20 MMBtu/hr boiler has been provided as an example.

III. Emissions Calculations

The emissions for the various boilers were calculated using the UDAQ's "Boiler - Natural Gas" emissions spreadsheet. This spreadsheet is available to the public and can be found on the Utah Department of Environmental Quality's (UDEQ) website under the Air Quality New Source Review Permitting Resources Section. This spreadsheet uses emissions factors from AP-42 Table 1.4-1 and Table 1.4.2 to calculate criteria pollutant emissions and AP-42 Table 1.4-3 and Table 1.4-4 to calculate Hazardous Air Pollutant (HAP) emissions. Furthermore, emission rates of NOx and Carbon Monoxide (CO) can be adjusted by inputting the ppm concentration of the specific boiler's emissions. The NOx emissions of each boiler was calculated using the specific NOx emission rating in ppm according to the boiler's specifications.

The calculations were done assuming standard full-time operation because this is what is normally assumed in a permitting BACT analysis. This consists of 8,760 hours of operation per year firing normally as opposed to "tangentially".

IV. BACT Calculations

There are various values calculated and used in the "2-5 MMBtu/hr Cost Analysis" and ">5MMBtu/hr Cost Analysis" Spreadsheets (Appendices B & C). This section will explain each calculation and how it was derived.

The "Lifetime NOx Emissions (ton/yr)" was calculated by multiplying the yearly NOx emissions (from the Boiler - Natural Gas spreadsheet) by the lifespan of the new boiler. The lifespan of the various boilers is based on what the manufacturer claimed for that specific boiler. This equation is shown below:

$$Lifetime\ NOx\ Emissions = (Yearly\ NOx\ Emissions) \times (Equipment\ Lifespan)$$

The “Lifetime NOx Saving (tons/yr)” takes the lifetime NOx emissions of the boiler if it was running at 60 ppm NOx (standard - no lower NOx burners) and subtracts the lifetime NOx emissions if the boiler was running at the specified NOx rating (30 ppm or 9 ppm depending on the boiler). This allowed the UDAQ to calculate the potential lifetime NOx emissions reduction by using ultra-low NOx (9 ppm) or low-NOx (30 ppm) burners. This equation is shown below:

$$Lifetime\ NOx\ Saving = \frac{(Lifetime\ NOx\ emissions\ at\ 60\ ppm)}{(Lifetime\ NOx\ emissions\ (30\ or\ 9\ ppm))}$$

Next, the BACT cost (cost per ton of NOx removed) was calculated a few different ways depending on what NOx ppm rating quotes UDAQ received for that specific boiler setup. A worst-case scenario BACT cost was calculated for all ultra-low NOx and low-NOx quotes received. This cost analysis took the entire cost of the new ultra-low NOx or low-NOx boiler and divided it by the lifetime NOx savings. This number was calculated to show the highest potential cost if the only way to get the boiler to 9 ppm NOx was to do a full replacement. This equation is shown below:

$$Worst\ Case\ Scenario\ BACT\ Cost = \frac{(Cost\ of\ new\ boiler)}{(Lifetime\ NOx\ Emissions\ Savings)}$$

Furthermore, the actual BACT cost (the cost increase to use an ultra-low NOx burner) was calculated where enough cost information was received. The “BACT Cost Analysis from Normal (60 ppm) to Ultra-Low NOx (9 ppm)” was calculated when a quote was received for both a 60 ppm burner and a 9 ppm burner on the given specific boiler. To calculate this the “Cost Differential” was first calculated. This equation is shown below:

$$Cost\ Differential = (Cost\ of\ 9\ ppm\ boiler\ setup) - (Cost\ of\ 60\ ppm\ boiler\ setup)$$

From here the BACT cost was calculated. This equation is shown below:

$$BACT\ Cost\ (60\ ppm\ to\ 9\ ppm) = \frac{(Cost\ Differential)}{(Lifetime\ NOx\ Savings)}$$

Additionally, the “BACT Cost Analysis from Low-NOx (30 ppm) to Ultra-Low NOx (9 ppm)” was also calculated when a quote was received for both a 30 ppm burner and a 9 ppm burner on the given specific boiler. To calculate this the “Cost Differential” was first calculated. This equation is shown below:

$$Cost\ Differential = (Cost\ of\ 30\ ppm\ boiler\ setup) - (Cost\ of\ 60\ ppm\ boiler\ setup)$$

From here the BACT was calculated. This equation is shown below:

$$BACT\ Cost\ (30\ ppm\ to\ 9\ ppm) = \frac{(Cost\ Differential)}{(Lifetime\ NOx\ Savings)}$$

In some instances, the “Lifespan Annualized Cost” was calculated to compare it alongside the BACT costs. This cost was calculated by taking the cost of the equipment (or cost increase to upgrade to ultra-low NOx burners) and dividing it by the lifespan of the equipment. These costs were always lower than the BACT costs and were not used for cost analysis conclusions.

V. 2-5 MMBtu/hr Estimates

The UDAQ received seven different quotes on four specific boilers from three companies. The identities of the companies that provided the estimates will remain anonymous. The cost estimates for each quote are included in the “2-5 MMBtu/hr Cost Analysis” spreadsheet. This is included in Appendix B. All “worst-case scenario” and BACT costs are shown in $ per ton of NOx reduced. A Basic explanation of each specific quote is provided below:

Estimate #1:

The UDAQ received two quotes for a 3.34 MMBtu/hr water-tube boiler. One quote included a low-NOx (30 ppm) burner and one included an ultra-low NOx (9 ppm) burner. The low-NOx boiler was estimated to cost $75,000 and the ultra-low NOx boiler was estimated to cost $94,000. The worst-case scenario BACT cost for the ultra-low-NOx burner was calculated to be $5,164.84 and the BACT cost from going from a low-NOx burner to an ultra-low-NOx burner was calculated to be $2,567.57. According to the manufacturer, this equipment was expected to have a 20-year lifespan.

Estimate #2:

The UDAQ received two quotes for a 3.34 MMBtu/hr high-pressure steam boiler. One quote included a low-NOx (30 ppm) burner and one included an ultra-low NOx (9 ppm) burner. The low-NOx boiler was estimated to cost $139,000 and the ultra-low NOx boiler was estimated to cost $164,000. The worst-case scenario BACT cost for the ultra-low NOx burner was calculated to be $7,208.79 and the BACT cost from going from a low-NOx burner to an ultra-low NOx burner was calculated to be $2,702.70. According to the manufacturer, this equipment was expected to have a 25-year lifespan.

Estimate #3:

The UDAQ received two quotes for a 2.78 MMBtu/hr boiler. One quote included a 75 ppm NOx burner and one included an ultra-low NOx (9 ppm) burner. The 75 ppm boiler was estimated to cost $120,625 and the ultra-low NOx boiler was estimated to cost $202,500. The worst-case scenario BACT cost for the ultra-low NOx burner was calculated to be $10,331.63 and the BACT cost from going from the 75 ppm burner to an ultra-low NOx burner was calculated to be $4,177.30. According to the manufacturer, this equipment was expected to have a 25-year lifespan.

Estimate #4:

The UDAQ received one quote for a 3.4 MMBtu/hr boiler. This quote included an ultra-low NOx (9 ppm) burner. This boiler was estimated to cost $198,657. The worst-case scenario cost for this boiler was calculated to be $8,732.18.

VI. Greater than 5 MMBtu/hr Boilers

The UDAQ received three quotes from one manufacturer regarding three different boiler configurations. The UDAQ also included a retrofit cost analysis on a larger boiler. A basic explanation of each cost analysis is exampled below:
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Estimate #5

The UDAQ received three quotes for a 6.7 MMBtu/hr Boiler. The quotes were all for the same boiler but used various burners. One quote used a normal (60 ppm) burner, one used a low-NOx (30 ppm) burner, and one used an ultra-low NOx (9 ppm) burner. The costs for the various boiler setups are shown in the table below.

Boiler Setup	Cost
6.7 MMBtu/hr Normally (60 ppm)	$211,424.51
6.7 MMBtu/hr with Low-NOx (30 ppm)	$224,839.41
6.7 MMBtu/hr with Ultra-Low NOx (9 ppm)	$237,598.91

The worst-case scenario cost for the ultra-low NOx boiler was calculated to be $5,221.95. The BACT cost going from a standard (60 ppm) burner to an ultra-low NOx burner was calculated to be $575.26. The BACT cost going from a low-NOx (30 ppm) to an ultra-low NOx (9 ppm) was calculated to be $680.51.

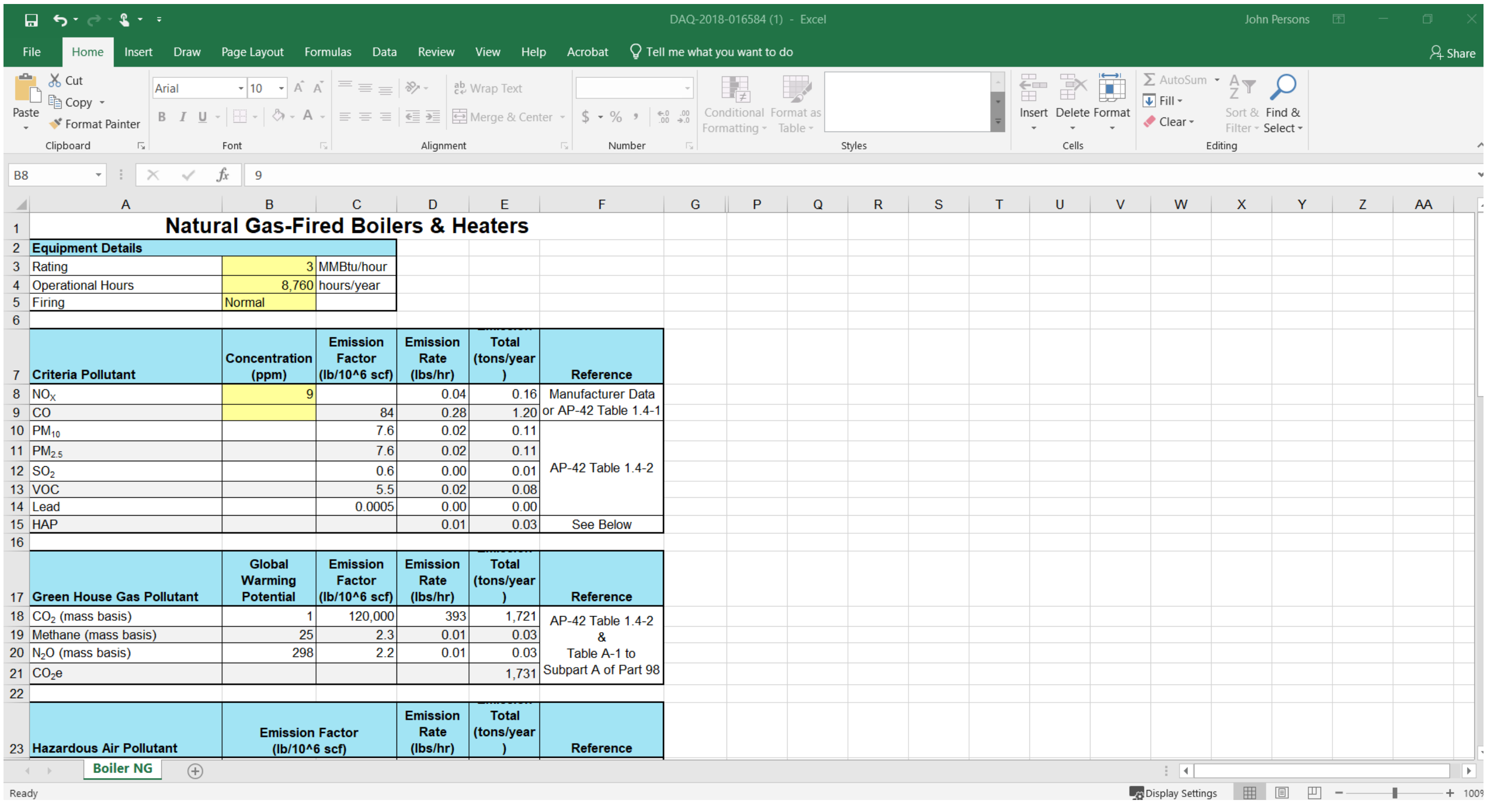
Estimate #6

This estimate was provided as an example of a retrofit of a 20 MMBtu/hr boiler from low-NOx (30 ppm) to ultra-low NOx (9 ppm). The pricing and emissions information is from a project the UDAQ worked on. The total cost retrofit the boiler was $212,178. The equipment had a lifespan of 20 years according to the manufacturer. The BACT cost from this quote was estimated to be $6,800 per ton of NOx removed.

VII. Conclusion

Based on the information provided above, the use of ultra-low NOx burners shows to be cost-effective for both categories of boilers (2-5 MMBtu/hr and >5 MMBtu/hr). The worst-case scenario costs for boilers between 2-5 MMBtu/hr were between $5,164 and $10,331. The calculated BACT cost for boilers between 2-5 MMBtu/hr was between $2,567 and $7,208. The worst-case scenario cost of boilers >5 MMBtu/hr was estimated to be $5,221.95, while the BACT cost for boilers greater than 5 MMBtu/hr was calculated to be between $575.26 and $680.51. Additionally, the retrofit cost analysis on a larger boiler also showed to be cost-effective. These numbers show that implementing ultra-low NOx burners on boilers in both size categories is cost-effective and should be selected as BACT. UDAQ recognizes that there may be instances in which the proposed 9 ppmv emission limit may be technically or financially infeasible and is considering including potential regulatory relief language in the rule, such as a BACT demonstration alternative allowing sources the opportunity to submit an analysis outlining challenges complying with this limit.

I. Appendix A



Natural Gas-Fired Boilers & Heaters

Equipment Details		
Rating	3	MMBtu/hour
Operational Hours	8,760	hours/year
Firing	Normal	

Criteria Pollutant	Concentration (ppm)	Emission Factor (lb/10^6 scf)	Emission Rate (lbs/hr)	Total (tons/year)	Reference
NO_X	9		0.04	0.16	Manufacturer Data or AP-42 Table 1.4-1
CO		84	0.28	1.20	
PM_{10}		7.6	0.02	0.11	AP-42 Table 1.4-2
$PM_{2.5}$		7.6	0.02	0.11	
SO_2		0.6	0.00	0.01	
VOC		5.5	0.02	0.08	
Lead		0.0005	0.00	0.00	
HAP			0.01	0.03	See Below

Green House Gas Pollutant	Global Warming Potential	Emission Factor (lb/10^6 scf)	Emission Rate (lbs/hr)	Total (tons/year)	Reference
CO_2 (mass basis)	1	120,000	393	1,721	AP-42 Table 1.4-2 & Table A-1 to Subpart A of Part 98
Methane (mass basis)	25	2.3	0.01	0.03	
N_2O (mass basis)	298	2.2	0.01	0.03	
CO_2e				1,731	

Hazardous Air Pollutant	Emission Factor (lb/10^6 scf)	Emission Rate (lbs/hr)	Total (tons/year)	Reference

II. Appendix B

1. Estimate #1

Boiler Information (Basic):		3.34 MMBtu/hr Low-Nox (30 ppm) Boiler		3.34 MMBtu/hr Ultra Low-Nox (9 ppm) Boiler		3.34 MMBtu/hr Standard (60 ppm) Boiler
						(For pollutant estimates only)
Boiler Information (Specific):	Manufacturer		Manufacturer		Manufacturer	
	Type:		Type:		Type:	
	BTu:	3.34 MMBtu/hr	BTu:	3.34 MMBtu/hr	BTu:	3.34 MMBtu/hr
	NOx Rating:	30 ppm	NOx Rating:	9 ppm	NOx Rating:	60 ppm
	Lifespan:	20 years	Lifespan:	20 years	Lifespan:	20 years
Pricing Information						
Product Price to Customer:		$75,000.00		$94,000.00		
Freight (CIP) Cost:		NA		NA		
Total Price to Customer:		**$75,000.00**		**$94,000.00**		
-	lbs/hr	Tons/yr	lbs/hr	Tons/yr	lbs/hr	Tons/yr
NOx	0.24	0.53	0.07	0.16	0.49	1.07
Lifetime Nox Emissions (tons/yr)		**10.6**		**3.20**		**21.4**
Lifetime Nox Savings (tons/yr):		**10.8**		**18.20**		**0**
(compared to 60 ppm boiler)						
Worst Case Scenario Cost Analysis						
BACT Cost ($/ton NOx removed)		**$6,944.44**		**$5,164.84**		
Lifespan Annualized Cost		$3,000.00		$3,760.00		
BACT Cost Analysis from Low-NOx (30 ppm) to Ultra Low-NOx (9ppm)						
Cost Differential				$19,000.00		
Tons/yr NOx reduction				7.40		
BACT Cost ($/ton NOx removed)				**$2,567.57**		
Annualized Cost				**$760.00**		
BACT Cost Analysis from Normal (60 ppm) to Ultra Low-NOx (9ppm)						
Cost Differential						
Tons/yr NOx reduction						
BACT Cost ($/ton NOx removed)						
Annualized Cost						

2. Estimate #2

Boiler Information (Basic):		3.34 MMBtu/hr Low-Nox (30 ppm) Boiler		3.34 MMBtu/hr Ultra Low-Nox (9 ppm) Boiler		3.34 MMBtu/hr Standard (60 ppm) Boiler
						(For pollutant estimates only)
Boiler Information (Specific):	Manufacturer		Manufacturer		Manufacturer	
	Type:		Type:		Type:	
	Btu:	3.34 MMBtu/hr	Btu:	3.34 MMBtu/hr	Btu:	3.34 MMBtu/hr
	NOx Rating:	30 ppm	NOx Rating:	9 ppm	NOx Rating:	60 ppm
	Steam Pressure:	150 PSI	Steam Pressure:	150 PSI	Steam Pressure:	150 PSI
	Lifespan:	25 years	Lifespan:	25 years	Lifespan:	25 years
Pricing Information						
Product Price to Customer:		$139,000.00		$164,000.00		
Freight (CIP) Cost:		NA		NA		
Total Price to Customer:		**$139,000.00**		**$164,000.00**		
-	lbs/hr	Tons/yr	lbs/hr	Tons/yr	lbs/hr	Tons/yr
NOx	0.24	0.53	0.07	0.16	0.49	1.07
Lifetime Nox Emissions (tons/yr)		13.25		4.00		26.75
Lifetime Nox Savings (tons/yr):		13.5		22.75		0
(compared to 60 ppm boiler)						
Worst Case Scenario Cost Analysis						
BACT Cost ($/ton NOx removed)		**$10,296.30**		**$7,208.79**		
Lifespan Annualized Cost		$5,560.00		$6,560.00		
BACT Cost Analysis from Low-NOx (30 ppm) to Ultra Low-NOx (9ppm)						
Cost Differential				$25,000.00		
Tons/yr NOx reduction				9.25		
BACT Cost ($/ton NOx removed)				**$2,702.70**		
Annualized Cost				$1,000.00		
BACT Cost Analysis from Normal (60 ppm) to Ultra Low-NOx (9ppm)						
Cost Differential						
Tons/yr NOx reduction						
BACT Cost ($/ton NOx removed)						
Annualized Cost						

3. Estimate #3

Boiler Information (Basic):		**2.78 MMBtu/hr Ultra Low-NOx (9 ppm) Boiler**		**2.78 MMBtu/hr (75 ppm) Boiler**
Boiler Information (Specific):	Manufacturer		Manufacturer	
	Type:		Type:	
	BTu:	2.78 MMBTu/hr	BTu:	2.78 MMBTu/hr
	NOx Rating:	9 ppm	NOx Rating:	75 ppm
	Lifespan:	25 years	Lifespan:	25 years
Pricing Information				
Product Price to Customer:		$202,500.00		$120,625.00
Freight (CIP) Cost:		NA		NA
Total Price to Customer:		**$202,500.00**		**$120,625.00**
-	lbs/hr	Tons/yr	lbs/hr	Tons/yr
NOx	0.24	0.13	0.07	1.11
Lifetime Nox Emissions (tons/yr)		**2.6**		**22.20**
Lifetime Nox Savings (tons/yr):		**19.60**		**-22.20**
(compared to 60 ppm boiler)				
Worst Case Scenario Cost Analysis				
BACT Cost ($/ton NOx removed)		**$10,331.63**		
Lifespan Annualized Cost		**$8,100.00**		
BACT Cost Analysis (75 ppm) to Ultra Low-NOx (9ppm)				
Cost Differential		$81,875.00		
Tons/yr NOx reduction		19.60		
BACT Cost ($/ton NOx removed)		**$4,177.30**		
Annualized Cost				

4. Estimate #4

Boiler Information (Basic):		3.34 MMBtu/hr Ultra Low-NOx (9 ppm) Boiler		60 ppm NOx Emissions
Boiler Information (Specific):	Manufacturer		Manufacturer	
	Type:		Type:	
	BTu:	3.34 MMBTu/hr	BTu:	
	NOx Rating:	9 ppm	NOx Rating:	
	Lifespan:	25 years	Lifespan:	
Pricing Information				
Product Price to Customer:		$198,657.00		
Freight (CIP) Cost:		NA		
Total Price to Customer:		**$198,657.00**		
-	lbs/hr	Tons/yr	lbs/hr	Tons/yr
NOx	0.24	0.16	0.07	1.07
Lifetime Nox Emissions (tons/yr)		**4**		**26.75**
Lifetime Nox Savings (tons/yr):		**22.75**		0.00
(compared to 60 ppm boiler)				
Worst Case Scenario Cost Analysis				
BACT Cost ($/ton NOx removed)		**$8,732.18**		
Lifespan Annualized Cost		$7,946.28		

III. Appendix C

1. Estimate #5

Boiler Information (Basic):		6.7 MMBtu/hr Low-Nox (30 ppm) Boiler		6.7 MMBtu/hr Ultra Low-Nox (9 ppm) Boiler		6.7 MMBtu/hr Standard (60 ppm) Boiler
Boiler Information (Specific):	Manufacturer		Manufacturer		Manufacturer	
	Model:		Model:		Model:	
	Application:	Steam	Application:	Steam	Application:	Steam
	Fuel Series:	Natural Gas	Fuel Series:	Natural Gas	Fuel Series:	Natural Gas
	MMBtu/hr	6.7 MMBtu/hr	MMBtu/hr	6.7 MMBtu/hr	MMBtu/hr	6.7 MMBtu/hr
	Design Pressure:	150 lb ST	Design Pressure:	150 lb ST	Design Pressure:	150 lb ST
	Operating Pressure:	125 psig	Operating Pressure:	125 psig	Operating Pressure:	125 psig
	Safety Valve Setpoint:	150 lb psig	Safety Valve Setpoint:	150 lb psig	Safety Valve Setpoint:	150 lb psig
	Gas NOx Emissions Level:	30 ppm	Gas NOx Emissions Level:	9 ppm	Gas NOx Emissions Level:	60 ppm
	Gas CO Emissions Level:	50 ppm	Gas CO Emissions Level:	50 ppm	Gas CO Emissions Level:	50 ppm
	Available Site Voltage:	460/3/60	Available Site Voltage:	460/3/60	Available Site Voltage:	460/3/60
	Available Site Gas Pressure:	138.5 in. w.c.	Available Site Gas Pressure:	138.5 in. w.c.	Available Site Gas Pressure:	138.5 in. w.c.
	Approximate Site Altitude:	4500 ft. ASL	Approximate Site Altitude:	4500 ft. ASL	Approximate Site Altitude:	4500 ft. ASL
	Insurance Requirements:		Insurance Requirements:		Insurance Requirements:	
	Lifespan:	25 years	Lifespan:	25 years	Lifespan:	25 years
Pricing Information						
Product Price to Customer:		$220,109.76		$232,600.51		$206,845.51
Freight (CIP) Cost:		$4,729.65		$4,998.40		$4,579.00
Total Price to Customer:		$224,839.41		$237,598.91		$211,424.51
-	lbs/hr	Tons/yr	lbs/hr	Tons/yr	lbs/hr	Tons/yr
NOx	0.24	1.07	0.07	0.32	0.49	2.14
Lifetime Nox Emissions (tons/yr)		26.75		8		53.5
Lifetime Nox Savings (tons/yr): (compared to 60 ppm boiler)		26.75		45.5		0
Worst Case Scenario Cost Analysis						
BACT Cost ($/ton NOx removed)		$8,405.21		$5,221.95		
Lifespan Annualized Cost		$8,993.58		$9,503.96		
BACT Cost Analysis from Low-NOx (30 ppm) to Ultra Low-NOx (9ppm)						
Cost Differential				$12,759.50		
Tons/yr NOx reduction				18.75		
BACT Cost ($/ton NOx removed)				$680.51		
Annualized Cost				$510.38		
BACT Cost Analysis from Normal (60 ppm) to Ultra Low-NOx (9ppm)						
Cost Differential				$26,174.40		
Tons/yr NOx reduction				45.5		
BACT Cost ($/ton NOx removed)				$575.26		
Annualized Cost						

2. Estimate #6

Boiler Information (Basic):	**20 MMBtu/hr Low-Nox (30 ppm) Boiler**		**20 MMBtu/hr Ultra Low-Nox (9 ppm) Boiler Retrofit**	
Boiler Information (Specific):	**Manufacturer**		**Manufacturer**	
	Model:		**Model:**	
	Application:	Steam	**Application:**	Steam
	Fuel Series:	Natural Gas	**Fuel Series:**	Natural Gas
	MMBtu/hr	20 MMBtu/hr	**MMBtu/hr**	20 MMBtu/hr
	Lifespan:	30 Years	**Lifespan:**	30 Years
Pricing Information				
Product Price to Customer:				$212,178.00
Freight (CIP) Cost:				
Total Price to Customer:				**$212,178.00**
-	**lbs/hr**	**Tons/yr**	**lbs/hr**	**Tons/yr**
NOx		1.49	0.07	0.45
Lifetime Nox Emissions (tons/yr)		**44.7**		**13.5**
Lifetime Nox Savings (tons/yr):				**31.2**
(compared to 60 ppm boiler)				
BACT Cost Analysis from Low-NOx (30 ppm) to Ultra Low-NOx (9ppm)				
Cost Differential				$212,178.00
Tons/yr NOx reduction				31.2
BACT Cost ($/ton NOx removed)				**$6,800.58**
Annualized Cost				**$8,487.12**